Characterizing Variability in the Distribution of High-Frequency Acoustic Backscattering in a Shallow Water Coastal Region

Gareth L. Lawson
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-3649 fax: (508) 457-2134 email: glawson@whoi.edu

Timothy K. Stanton
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2757 fax: (508) 457-2194 email: tstanton@whoi.edu

Peter H. Wiebe
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2313 fax: (508) 457-2169 email: pwiebe@whoi.edu

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LONG-TERM GOALS

The central goal of this project is for the Primary Investigator, Gareth Lawson, to design, execute, and defend his doctoral thesis research. In terms of its scientific purpose, this research seeks to contribute to our understanding of spatial and temporal patchiness in the distribution of high-frequency acoustic volume backscattering stemming from zooplankton (e.g., Figure 1).

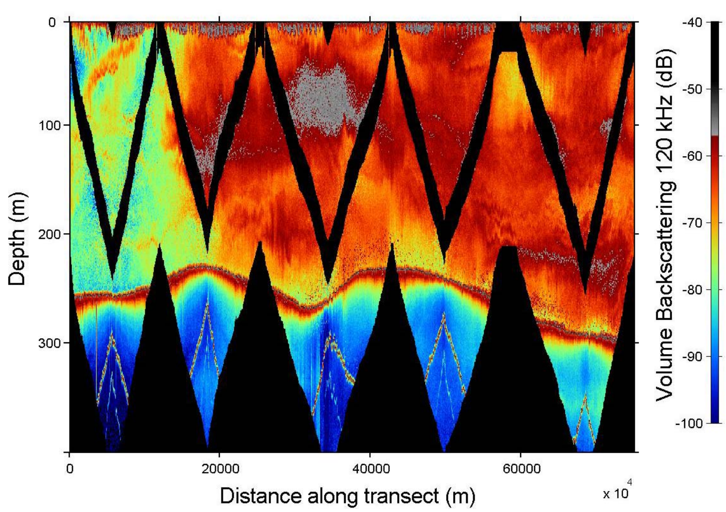

Figure 1: Volume backscattering (dB) measured at 120 kHz in Georges Basin, December 1999, showing distinct spatial patchiness both along-transect and with depth.

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OBJECTIVES

The objectives of the project are three-fold: 1. To quantify the spatial and temporal variability in the distribution of acoustically-inferred zooplankton biomass in shallow water coastal regions. 2. To assess the predictability and persistence of such patchiness, and understand its association with physical and biological oceanographic processes. 3. To continue the process of field-testing and refining models of zooplankton acoustic scattering.

APPROACH

The overall approach is to apply the models of zooplankton scattering developed at Woods Hole Oceanographic Institution (WHOI) to multi-frequency volume backscattering data collected in continental shelf regions under other research projects, in order to infer zooplankton abundance and biomass by size group. These estimates of zooplankton abundance and distribution are then compared between times and regions to assess patterns in variability. The areas under study include a continental shelf region west of the Antarctic Peninsula and the Gulf of Maine. At both sites, the data used for analysis were collected with the WHOI BIo-Optical Multi-frequency Acoustical and Physical Environment Recorder (BIOMAPER-II).

An important aspect of the research has involved the development of protocols for distinguishing the scattering of the various zooplankton taxa present, delineating aggregations within the acoustic record attributable to single zooplankton species, and estimating the size, abundance, and biomass of animals within such aggregations. Presently, these methodologies are being applied to the various datasets available, and the resulting measurements of zooplankton distribution and patch structure are being compared between times and regions, and examined in light of other physical and biological processes studied concurrently during the cruises. While the distribution of zooplankton in general continues to be a topic of study under the project, particular emphasis has come to be placed on the distribution and patchiness of euphausiids, notably the Antarctic krill (*Euphausia superba*).

This award was given to allow the Primary Investigator, Gareth L. Lawson, to pursue his doctoral thesis research. The Co-Primary Investigators, Timothy K. Stanton and Peter H. Wiebe, act as thesis advisors.

WORK COMPLETED

Substantial progress was made in this third year towards completing the project’s objectives. The first paper from the project was published in Deep-Sea Research II, based on analyses conducted in the project’s first year of the broad-scale distribution of acoustic volume backscattering in the antarctic study region.

Much of the project has made use of existing scattering models and parameterizations for interpreting observed backscattering levels. In the case of Antarctic krill, however, an investigation was made into improving the parameterization of a Distorted-Wave Born Approximation-based scattering model. Particular attention was given to the parameters governing the orientation of the animal relative to the incident acoustic wave and its acoustic material properties: parameters that have important effects on predicted scattering but about which there has historically existed a great deal of uncertainty. Direct measurements of the orientation of krill made with a Video Plankton Recorder (VPR) were used to constrain the parameter governing the orientation of the animal. Recently published length-based

regressions were used to constrain the material properties, rather than the earlier approach of using single parameter values for all lengths. A manuscript stemming from these investigations has been conditionally accepted to the Journal of the Acoustical Society of America.

Analyses conducted during the project's first year of expected backscattering levels predicted from depth-stratified net samples made at the antarctic study site suggested that observed backscattering stemmed from a complex mixture of zooplankton taxa. Therefore, based on the newly parameterized theoretical scattering model described above, a protocol was developed to distinguish krill aggregations from other sources of scattering based on differences in scattering at four acoustic frequencies (43, 120, 200, and 420 kHz). A method was also developed to delineate the boundaries of krill aggregations, via threshold levels of scattering determined from the theoretical basis of krill visual acuity. Measurements of patch features (e.g., position, shape, internal structure) are then made on krill aggregations identified in this way. An exploration was made of simple inverse techniques for estimating the length and abundance of krill in these identified aggregations, assuming that the patches are composed of a single species of a uni-modal length distribution. These methods represent a refinement of protocols developed during the project's second year, and have been verified with VPR observations as well as net catches from a 1-m^2 MOCNESS trawl.

In addition to the main thesis project, the Primary Investigator was involved in a number of collaborations, including studies on the distribution of higher predators (seabirds, seals, and whales) in relation to their zooplankton prey, and an examination of the genetic composition of krill patches. One manuscript based on a comparison of whale distribution to zooplankton volume backscattering has been submitted to Marine Ecology Progress Series.

RESULTS

Analyses of the broad-scale distribution of zooplankton backscattering in the antarctic continental shelf study region revealed strong seasonal and spatial variability during the falls and winters of 2001 and 2002, much of which appears to be understandable in light of meso-scale circulation. Four general types of scattering features were evident across the region: 1) large bottom-associated patches found in regions of variable bathymetry in coastal regions, 2) smaller discrete patches found primarily in the surface mixed layer across much of the shelf, 3) deep diffuse patches found near the shelf-break and northern shelf region, and 4) deep homogeneous scattering layers situated over the southern portion of the study area. On the basis of the multi-sensor methodologies described above, the first two feature types appear to stem from aggregations of euphausiids. The third type remains under investigation, but at present the evidence points towards myctophid fishes as being the dominant scatterer. The available evidence concerning the deep southern scattering layers is less conclusive. These layers appear to consist of a quite complex mixture of zooplankton taxa, perhaps with a certain dominance by copepods and gas-bearing siphonophores.

Similar analyses of multi-frequency volume backscattering data collected in the Gulf of Maine during the falls of 1997-1999 have revealed strong inter-annual and spatial variability, both of which differ between acoustic frequencies. Mean backscattering levels do not reflect the decrease in the abundance of the ecologically-important copepod *Calanus finmarchicus* observed in net catches in the fall of 1998 relative to the falls of 1997 and 1999. An increase in the abundance of the predators and competitors of *C. finmarchicus* may have served to keep backscattering levels high during this period. Distinct patterns and diel changes were evident in the vertical distribution of backscattering, although these differed between basins and years.

As indicated above, theoretical model predictions of Antarctic krill target strength are strongly influenced by the parameters governing the animal's orientation and acoustic material properties. The investigation seeking improved parameterization of a theoretical scattering model for krill found that krill oriented themselves mostly horizontally. Parameterizing the scattering model with the observed distribution of orientations, together with recently published information on krill acoustic material properties, resulted in predictions of target strength more consistent with *in situ* measurements of krill target strength than earlier parameterizations (Figure 2). These predictions were smaller, however, than expected under the semi-empirical model traditionally used to estimate krill target strength (Figure 2). Use of this semi-empirical model in estimating krill abundance thus could result in estimates too low by a factor of at least 2.75.

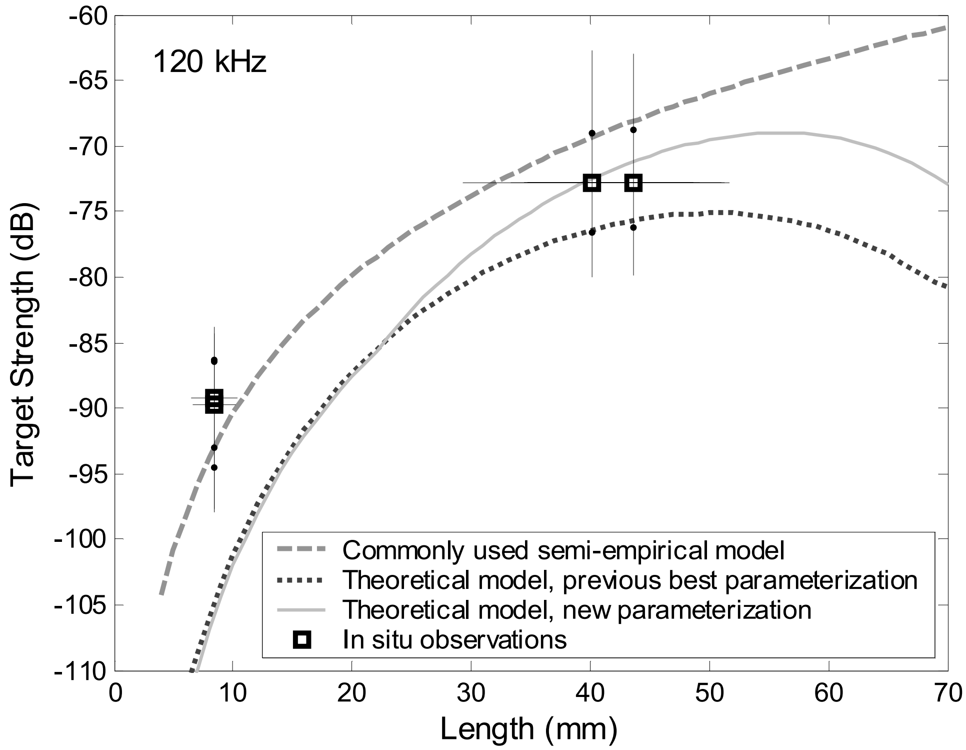

Figure 2: Antarctic krill target strength (dB) at 120 kHz in relation to animal length.

Application of the protocols based on this newly-parameterized scattering model for identifying krill patches and estimating the length and abundance of animals is ongoing; the preliminary results of krill patch distribution and structure are very exciting. In fall, many small patches appear to be distributed widely across the antarctic shelf, with a few much larger patches found in coastal areas and regions of highly variable bathymetry (Figure 3).

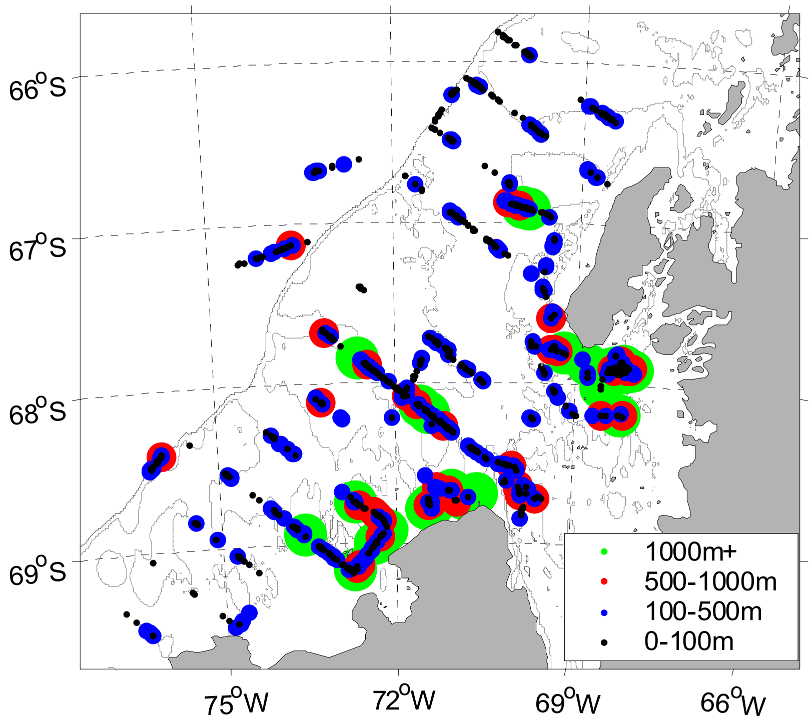

Figure 3: Distribution of Antarctic krill aggregations in fall, 2001 along the Western Antarctic Peninsula. Dot size and color indicate aggregation length.

IMPACT/APPLICATIONS

The project will result in a detailed understanding of variability in the distribution of zooplankton backscattering, ultimately allowing such variability to be modeled and predicted. This constitutes an essential step in constraining the uncertainty introduced into Navy representations of the acoustic field by these important scatterers, and in understanding the implications of zooplankton patchiness relative to the distribution of predators, including marine mammals and exploited fish species. Most of the present research has made use of existing scattering models. Through comparisons of acoustic data to video and net samples, an approximate model for Antarctic krill has been further evaluated and better parameterized. The outcome is a field-tested acoustic scattering model of a complex, naturally occurring scatterer.

RELATED PROJECTS

The development of the BIOMAPER-II and its use in a series of cruises in the Gulf of Maine were funded in part by the ONR (Grant Numbers N00014-95-11102, N00014-98-1-0362, and N00014-97-1-0646), and in part by NOAA (Grant 31654-5717). Additional data under analysis were collected with the BIOMAPER-II in the Antarctic, as part of the Southern Ocean GLOBEC program (NSF Office of Polar Programs Grant OPP-9910307). Some of the methodologies developed in the present project are also being applied to data collected during the U.S. Georges Bank GLOBEC program, as part of synthesis analyses funded by NOAA (Cooperative Institute for Climate and Ocean Research Grant

NA17RJ1223). The zooplankton scattering models employed in the project were originally developed under a number of ONR-funded projects (primarily Grant N00014-95-1-0287).

PUBLICATIONS

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